The Impact of Compactive Effort on the Long Term Hydraulic Conductivity of Compacted Foundry Sand Treated with Bagasse Ash and Permeated with Municipal Solid Waste Landfill Leachate

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Abstract

This paper presents a study on the influence of compactive effort on long term hydraulic performance of compacted foundry sand treated with bagasse ash, with specimens permeated with municipal solid waste (MSW) landfill leachate in sequence. Based on the hydraulic conductivity, results obtained for bagasse ash treated foundry sand at optimum molding water content of only 2 and 4% treatment level which met specification requirements at the four energy levels of reduced British standard light (RBSL), British standard light (BSL), West African Standard (WAS), and British Standard heavy (BSH). Therefore, foundry sand specimens at 2 and 4% bagasse ash content and compacted at the four energy levels of reduced British standard light (RBSL), British standard light (BSL), West African Standard (WAS), and British Standard heavy (BSH) (relative compaction = 100%), were permeated with municipal solid waste (MSW) landfill leachate in sequence at 2% wet of optimum moisture content to assess the influence of the four compactive efforts on the long term hydraulic performance of compacted bagasse ash treated foundry sand. The falling head testing method was used, while the experiments were terminated after 90 days when steady flows had been established. At 2 % bagasse ash treated foundry sand, lower energy levels recorded more decrease in the final hydraulic conductivity values by the factors of 1.46, 1.33, 1.08 and 1.00 for RBSL, BSL, WAS and BSH compactive efforts, respectively. 4 % bagasse ash treated foundry sand gave factors of 1.61, 1.32, 1.17 and 0.70 for RBSL, BSL, WAS and BSH compactive efforts, respectively. Lower energies levels have less pore or voids after long period of hydration reaction due to products of formed hydrations (cementitious compounds) filling the pores: bigger pores experience greater impact on their pores due to hydration reaction products filling up the available pores than specimen at higher compactive effort. Therefore, the final hydraulic conductivity values record greater changes than those of specimens compacted at higher energy levels. It is important to note that the pores of pozollana-soil mixtures if cured for longer period's decreases and hydration products decrease void space with curing times. Therefore, hydraulic conductivity of compacted foundry sand treated with bagasse ash in the long term is more affected at lower energy level than that at higher energy levels. Thus, for bagasse ash treated foundry sand, the lower energy levels are the most suitable to adopt in the construction of liners and covers based on experimental results recorded.

Keywords

Bagasse ash; Compaction; Hydraulic Conductivity

Introduction

Hydraulic conductivity and its vulnerability to changes with time or exposure to chemicals are the major factors in the selection of materials for barrier systems in waste containment facilities. Compatibility of a liner material with leachate is a very important consideration in the design of waste containment facilities. The waste containment system must be able to maintain its strength and regulatory hydraulic conductivity value after prolonged contact with leachate. A large change in hydraulic conductivity (k) is an indication that the waste leachate and soil are not compatible. Particles are highly susceptible to changes in moisture and to physic chemical interactions with the liquid to be contained (Kenny et al., 1992; Egloffstein, 2001; Mesri and Olson, 1971 Acar and Oliveri, 1990; Shackelford, 1994; O'Sadnick, 1995; Chen et al., 2000; Shackelford et al., 2000; Frempong and Yanful, 2008).

Significant increase in hydraulic conductivity may result from flocculation of clay particles due to interaction with electrolyte solution, shrinkage of the soil matrix in the presence of concentrated organic solvents and acid-base dissolution of the soil. Shackelford (1994) also suggested that the final hydraulic conductivity value after permeation with the waste liquid (k_f) established by permeating the soil with water should not result in a large change.

The traditional selection and performance criteria for assessing the technical suitability of materials meant for hydraulic barriers in waste disposal facilities are low hydraulic conductivity, adequate shear strength and low potential for desiccation cracks and volumetric shrinkage (Rowe *et al.,* 1995; Daniel and Wu, 1993; Edil *et a.l*, 1992; Daniel and Benson, 1990;). However, one other fundamental design requirement and testing consideration is the compatibility between the material and the fluid to be contained (Shackelford *et al*., 2000). This interaction is better understood through a compatibility test, which is usually made by means of hydraulic conductivity testing. Compatibility refers to the potential effect of chemical interactions between the permeating liquid and the porous material on the properties of the material. Drastic changes in hydraulic conductivity are an indicator of incompatibility. In cases of adverse results, stabilizing materials such as relatively non-reactive clays, organic modifiers or polymers may be incorporated to prevent drastic increases in hydraulic conductivity (Evans, 1993; Shackelford and Jefferis, 2000).

There are reported cases of high values of hydraulic conductivity in the field and in some cases failures of containment facilities traceable to compatibility problems (e.g., Daniel and Brown, 1988; Goldman *et al*., 1986,). Most geological materials that contain these clay minerals are found to be naturally reactive resulting in greater adsorption characteristics and double layer expansion and this exerts considerable influence on the hydraulic conductivity both in short and long term. This influence has been explained by the double layer theory (Rowe *et al*., 1995; Shackelford *et al*., 2000). In the interaction between day particles and the surrounding pore fluid, the net electrical charge on clay particles is negative (Shackelford, 1994) which causes hydrated cations in the surrounding pore water to be attracted to the surfaces of the clay, of which water and adsorbed ions that surrounds a clay particle is referred to as the electrical double layer or diffuse double layer (Shackelford, 1994). A double layer contraction at constant void ratio (flocculation) creates a large increase in free void space, which may cause increases in hydraulic conductivity. Conversely, a chemical change that peptizes, disperses or expands the double layer may eliminate most of the free space and reduce hydraulic conductivity (Rowe *et al.,* 1995).

There are two basic types of available foundry sand, green sand (often referred to as molding sand) that uses clay as the binder material, and chemically bonded sand that uses polymers to bind the sand grains together. Green sand consists of 85 – 95% silica, 0–12% clay (bentonite, kaolin etc), 2–10% carbonaceous additives, such as sea coal, and 2–5% water, other minor ingredients (flour, rice hulls, starches, cereals, etc.) may be added to absorb moisture, improve the fluidity of the sand, or stiffen the sand based on the production needs of the individual foundry. Green sand is the most commonly used moulding media in foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. The water adds plasticity; however spent foundry sand has no plasticity (Johnson, 1981).

Sugar cane is a major raw material for sugar production. It grows 25–30,000 hectares in Nigeria with a production rate of about 80 tons/hectare (Misari et al., 1998). Bagasse is the fibrous residues obtained from sugar cane after the extraction of sugar juice at sugar cane mills. While bagasse ash is the residue obtained from the incineration of bagasse in sugar producing factories. Bagasse ash has been shown to posses pozzolanic properties (Medjo and Riskowski, 2004; sujjavanidi and Duangehan. 2004; Osinubi and Stephen, 2005). Research works have been carried out on the improvement of geotechnical characteristics of soils using bagasse ash (Osinubi and Stephen, 2006a,b, 2008; Stephen, 2006).

The objective of this study is to investigate the influence of compactive effort on the long term hydraulic performance of compacted bagasse ash treated foundry sand as liner in municipal solid waste containment facility with specific emphasis on saturated hydraulic conductivity. The limitations of the study is the absence of consideration of the post permeation mineralogy of the bagasse ash treated foundry sand mixtures. This study aims at assessing the impact of compactive energy level on long term hydraulic performance of compacted foundry sand treated with bagasse ash as a liner and cover material.

Materials and Methods

Materials

Foundry sand: The foundry sand used in this study was obtained from Defense Industries Corporation of Nigeria (DICON) industries, in Kaduna State of Nigeria. The location lies within latitude 10° 30′N and longitude 7°27′E. Specimens were varied with 2 and 4% of bagasse ash by dry weight of soil.

Bagasse ash: The bagasse ash utilized in this work was obtained from Anchau Local Government Area of Kaduna State, Nigeria. Bagasse husks (i.e. the residue after extraction of the sugar juice) was openly incinerated with in a temperature range of 500^0-700^0C.

TABLE 1 OXIDE COMPOSITION OF BAGASSE ASH

Oxide	**Concentration (%)**
CaO	3.2
SiO_2	57.1
Al_2O_3	29.7
Fe_2O_3	2.75
Na_2O+K_2O	8.72
TiO_2	1.10
SO_3	0.04
LOI	17.41

(Osinubi et ai., 2007)

Leachate: The leachate used in this study was obtained from a non engineered active open landfill located outside the premises of Ahmadu Bello University, Zaria, Nigeria. Generally the generated waste is from students, staff and others which are dumped at the site. Furthermore, the quality of the waste dumped in terms of its ability to generate high concentration leachate cannot be compared to that from a city landfill with higher population and volume of generated waste. The leachate, which can be classified as stabilized based on the foregoing, was collected by scooping from a low lying open point in the landfill. A summary of the chemical properties of the MSW landfill leachate is given in TABLE 2.

Methods

Index Properties: Laboratory tests were conducted to determine the index properties of the natural soil and soil – bagasse ash mixtures in accordance with British Standards BS 1377 (1990) and BS 1924 (1990) respectively. Particle size plot of the natural soil and soil – bagasse ash mixtures is shown in FIG. 1. A summary of the soil index properties is presented in TABLE 3.

TABLE 2 CHEMICAL CHARACTERISTICS OF LEACHATE

Parameters (Mg/L)	**Concentration (%)**
Na	6.5
K	15.1
Mg	0.8
Ca	1.2
Pb	0.8
Cr	1.2
Cl	2040
COD	2000
BOD	1000
TDS	4000
pH	10.0
LOI	17.41

Preparation of Specimens: The foundry sand was pulverized sufficiently to run through the BS No. 4 (4.76 mm aperture) sieve. Next percentages of 2 and 4% of bagasse ash by dry weight of soil were mixed to a uniform color. And tap is added at +2% (2% wet of optimum moisture content and thoroughly mixed until a uniform consistency was achieved).

Compaction: The used compactive energy level is the reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) British standard heavy (BSH). Test involving moisture – density relationship, volumetric shrinkage. Air dried soil samples passing through BS sieve with 4.76mm aperture mixed with 2% and 4% bagasse ash by weight of dry soil were used. The reduced British standard light is the effort derived from 2.5kg rammer falling through 30cm onto three layers, each receiving 13 uniformly distributed blows; (BS 1990). The British standard light is the effort derived from 2.5kg rammer falling through 30cm onto three layers, each receiving 27 uniformly distributed blows (BS 1990). The West African standard compactive effort (WAS) was carried out using energies derived from a rammer of 4.5 kg mass falling through a height of 45 cm in a 1000 cm^3 mould. The soil was compacted in five layers, each layer receiving 10 blows. The WAS compaction, was carried out using energies derived from a rammer of 4.5 kg mass falling through a height of 45 cm in a 1000 cm^3 mould. The soil was compacted in five layers, each layer receiving 10 blows. Finally, the BSH compaction were determined using energy derived from a hammer

of 4.5kg mass falling through a height of 45cm in a 1000cm³ mould. The soil was compacted in 5 layers, each receiving 27 blows.

Hydraulic Conductivity

This was measured using the rigid wall permeameter under falling head condition as recommended by Head (1992). A relatively short sample was connected to a standpipe, which provided the head of water flowing through the sample. Specimens were compacted using the RBSL, BSL, WAS and BSH compactive efforts. The soil–bagasse ash samples at 2% and 4% bagasse ash content were molded at water contents of +2% of the OMC. Specimens were soaked in a water tank for a minimum period of 24 hours to allow for full saturation and the samples were restrained from swelling vertically during saturation. The fully saturated test specimen was then connected to a permeant liquid (90 days). During permeation, test specimens were free to swell vertically (i.e., no vertical stress was applied).

Discussion of Results

Index properties

The index properties and compactions of the untreated and treated foundry sand are shown in TABLE 2. The particle size distribution curves are shown in FIG. 1. The non-plastic sand is classified as A-2-4 according to AASHTO classification system and SM according to the Unified Soil Classification System. The liquid limit initially slightly decreased in value from 19 to 18% and later increased to a peak value of 23.3% at 4% bagasse ash treatment. This increase can be attributed to the increase in water absorption or changes in the particle packing of the mixture. Beyond 4% bagasse ash content the liquid limit reduced in value. Foundry sand has been reported by Johnson (1981) failing to possess plasticity, largely due to the presence of a high percentage of fine sand and also the bentonite that was subjected to high temperature. Treatment of foundry sand with bagasse ash did not improve its plasticity, while the linear shrinkage was not significantly affected since the soil is predominantly sand.

Maximum Dry Density

There was a general decrease in maximum dry density for all the four energy levels as shown in FIG. 2. The MDD generally decreased with higher bagasse ash treatment up to 8% especially for BSL and BSH compactive effort. This could probably be as a result of

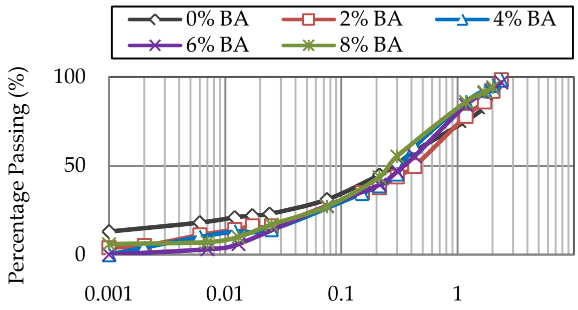

FIG. 1 PARTICLE SIZE DISTRIBUTION CURVE FOR NATURAL AND TREATED FOUNDRY SAND

TABLE 3 INDEX PROPERTIES OF TREATED AND UNTREATED FOUNDRY SAND

Engineering Properties	Bagasse ash content (%)				
	0	2	4	6	8
LIQUID LIMIT	19.0	18.0	23.3	19.4	18.8
PLASTIC LIMIT	N.P.	N.P	N.P.	N.P	N.P
PI	N.P.	N.P.	N.P.	N.P.	N.P.
LINEAR SHRINKAGE,	0.9	1.0	0.0	0.9	0.7
% PASSING BS NO. 200 SIEVE.	31	26.5	27	27.5	26.5
AASHTO	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-2-4(0)
USCS	SM	SM	SM	SM	SM
Gs	2.64	2.65	2.66	2.60	2.56
MDD Mg/m³					
RBSL	1.91	1.84	1.83	1.86	1.91
BSL	1.96	1.89	1.89	1.88	1.89
WAS	2.00	1.92	1.92	1.97	1.91
BSH	2.08	2.08	2.05	1.99	1.99
OMC%					
RBSL	12.0	12.5	13.0	13.0	13.0
BSL	11.5	11.6	11.7	12.0	12.2
WAS	9.5	8.6	9.5	10.0	11.3
BSH	8.3	8.6	7.7	8.6	8.3
PH VALUE	8.9	9.9	10.2	10.6	10.8
COLOUR	Brown				
DOMINANT CLAY MINERAL	Smectite				

the low specific gravity value of 2.20 of bagasse ash (Osinubi and Stephen, 2008) compared to that of foundry sand which is 2.64. Finally, above 4 % bagasse ash content especially for RBSL and WAS, an increase in maximum dry density was observed which could possibly be as a result of the formation of new compounds.

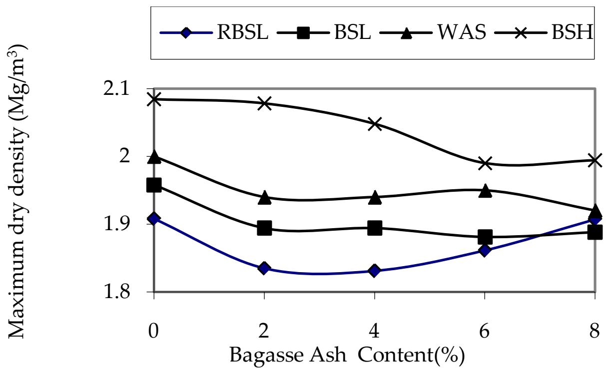

FIG. 2 VARIATION OF MAXIMUM DRY DENSITY OF FOUNDRY SAND WITH BAGASSE ASH CONTENT

Optimum Moisture Content

Generally, there is increase in the optimum moisture content (OMC) increased with higher bagasse ash content, except for an initial decrease observed for BSH the energy level as shown in FIG. 3, which was due to the increase in fines content resulting from the inclusion of bagasse ash with larger surface area that required more water to react. It also could be due to the larger amounts of water required for the hydration of bagasse ash. These results are in agreement with those reported by Nicholson and Kashyap (1993).

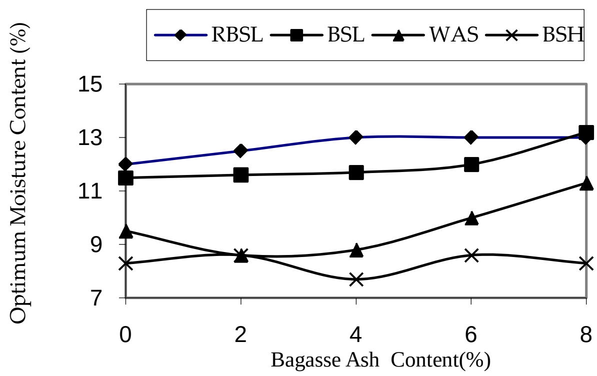

FIG. 3 VARIATION OF OPTIMUM MOISTURE CONTENT OF FOUNDRY SAND EITH BAGASSE ASH CONTENT

Effect of Bagasse Ash Content at Optimum Molding Water Content

The variation of hydraulic conductivity with bagasse ash content is shown FIG. 3. Hydraulic conductivity values of specimens increased from 0 to 2% bagasse ash treatment for all the energy levels; however it decreased at 4% bagasse that represents the optimum drop for all compactive efforts. Beyond 4% bagasse ash treatment hydraulic conductivity values increased possibly due to the presence of excess bagasse ash that would have changed the foundry sand matrix leading to increased flocculation (Osinubi and Eberemu, 2009b; Osinubi *et al.*, 2007). Higher compactive effort produced closer alignment of particles along the failure surface yielding decreased frequency of large voids that can conduct flow hence lower hydraulic conductivity (Amadi, 2003). Furthermore, Bowders and Daniel (1987) showed that fly ash particles filled the pore spaces between the larger sand particles to reduce the hydraulic conductivity of the mixture.

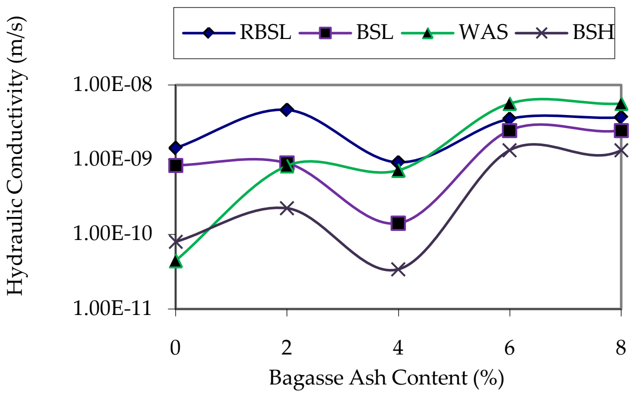

FIG. 4 VARIATION OF HYDRAULIC CONDUCTIVITY OF FOUNDRY SAND WITH BAGASSE ASH CONTENT

Influence of comp active Effort on the Hydraulic Conductivity of Municipal Solid Waste Leachate

Based on earlier results reported (see FIG. 5) on effect or impact of bagasse ash content at optimum molding water content on bagasse ash treated foundry sand, MSW landfill leachate (a multi-species solution) were introduced at 2 and 4% bagasse ash treatment alone (only the treatment levels of 2 and 4% produced successful hydraulic conductivity result). 2 % bagasse ash treated foundry sand (see FIG. 4) gave baseline hydraulic conductivity values of 2.81 x 10^{-9}, 8.35 x 10^{-10}, 4.98 x 10^{-10} and 1.70 x 10^{-10} m/s. Higher compactive effort produces a closer alignment of particles along the failure surface yielding decreased frequency of large voids that can conduct flow hence lower base line hydraulic conductivity with higher compactive effort (Amadi, 2003). While the final hydraulic conductivities after the 90 days duration were 1.93 x 10^{-9}, 5.67 x 10^{-10}, 3.69 x and 2.11 x 10^{-10} m/s for RBSL, BSL, WAS and BSH compactive efforts, respectively. The slight decreases in the hydraulic conductivity of

all the specimens with respect to each compactive effort were apparently suggesting partial entry of the leachate into the double diffuse layer. The lower energy levels recorded less decrease in the hydraulic conductivity values as indicated by the factors of 1.46, 1.33, 1.35 and 1.00 for RBSL, BSL, WAS and BSH compactive efforts, respectively.

4 % bagasse ash treated foundry sand gave baseline hydraulic conductivity values (see FIG. 5) of 4.13 x 10^{-8}, 3.44 x 10^{-9}, 2.42 x 10^{-9} and 4.90 x 10^{-10} m/s while the final hydraulic conductivity after the 90 days duration were 6.77 x 10^{-9}, 2.60 x 10^{-9}, 2.06 x 10^{-9} and 7.22 x 10^{-10} m/s for RBSL, BSL, WAS and BSH compactive efforts, respectively. The slight decreases in the hydraulic conductivity of all the specimens were apparently suggesting partial entry of the leachate into the double diffuse layer. The lower energy levels recorded less decrease in the hydraulic conductivity values as indicated by the factors of 1.61, 1.32, 1.17 and 0.70 for RBSL, BSL, WAS and BSH compactive efforts, respectively.

Generally, the result reflects the fact that lower energies levels have less pore or voids after long period of hydration reaction due to products of hydrations formed (cementitious compounds). The bigger pores experience greater impact on their pores than specimen at higher compactive effort. It is important to note that the pozollana-soil mixtures if cured for longer periods, their permeability could decrease even further because of the growing reaction products and reduced connected voids [Todres et al., 1992]. Thus, lower compactive efforts have more voids to occupy. XRD (x-ray diffraction) and SEM (scanning electron microscopy) investigations conducted on the pozollana -stabilized clays showed the presence of hydration products and a subsequent decrease in void space with curing times. Kamon and Nontananandh (1991) have suggested that in order for reactions to take place, the hydration modulus must be [1.7]. The hydraulic modulus of the bagasse specimen used in this study is greater than 1.7. Foundry sand and lime from bagasse ash under an alkaline condition provides a conductive environment for the dissolution of silicates and aluminates in the soil which reacts with Ca^{+2} cations to form cementitious compounds, through the hydration process.

Shackelford (1994b) also suggested that the final hydraulic conductivity value after permeation with the waste liquid (K_f) established by permeating the soil with water should not result in a large change. Finally, from a practical perspective, no change in hydraulic conductivity can be said to have occurred during the tests conducted with MSW landfill leachate since there increase in the hydraulic conductivity value. From this result, it can be inferred that the consequence of long-term exposure of bagasse ash treated foundry sand mixtures to MSW landfill leachate is beneficial to the safety of the liner system due to the decrease in the final hydraulic conductivity value. MSW landfill leachates generally have no detrimental impact on hydraulic conductivity of compacted soils (Osinubi and Nwaiwu,2005).

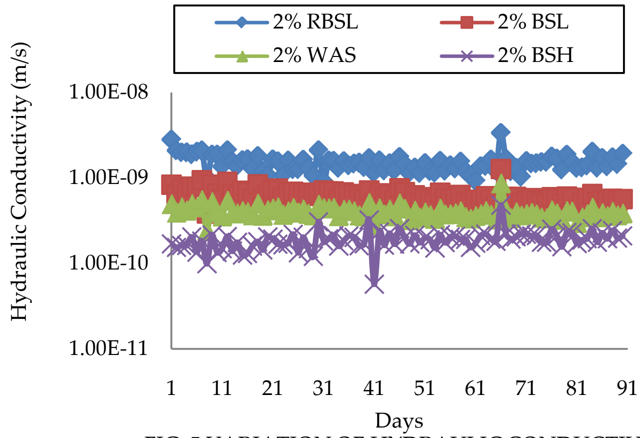

FIG. 5 VARIATION OF HYDRAULIC CONDUCTIVITY WITH TIME (AT FOUR DIFFERENT COMPACTIVE EFFORT AND 2% BAGASSE ASH TREATMENT) FOR 90 DAYS

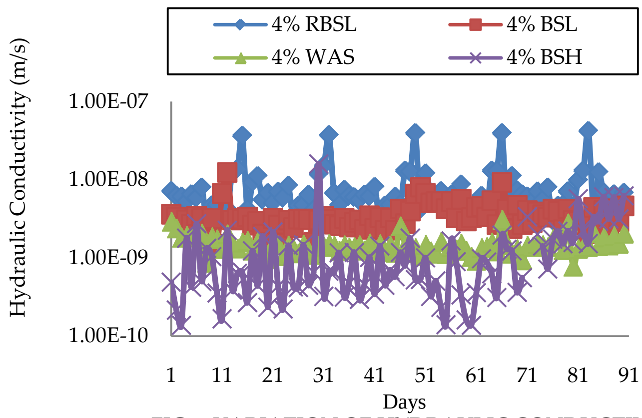

FIG. 5 VARIATION OF HYDRAULIC CONDUCTIVITY WITH TIME (AT FOUR DIFFERENT COMPACTIVE EFFORT AND 4% BAGASSE ASH TREATMENT) FOR 90 DAYS

Conclusion

The non-plastic foundry sand was classified as A-2-4 (0) and SM according to AASHTO and USCS, while bagasse ash treatment of foundry sand did not significantly improve the index properties of the mixtures. Generally, MDD and OMC decreased and increased, respectively, with higher bagasse ash

content. Hydraulic conductivity values of specimens increased beyond 4% bagasse ash treatment for all the four energy levels. Hydraulic conductivity values increased possibly due to the presence of excess bagasse ash that would have changed the foundry sand matrix leading to increased flocculation. Higher compactive effort generally produces closer alignment of particles along the failure surface yielding decreased frequency of large voids that can conduct flow, hence lower hydraulic conductivity at higher compactive effort.

Based on impact of bagasse ash content at optimum molding water content on treated foundry sand with MSW landfill leachate (a multi-species solution), 2 and 4% bagasse ash treatment were selected in order to examine the impact of the influence of compactive effort on the long term hydraulic conductivity performance of bagasse ash-foundry sand mixtures . 2 % bagasse ash treated foundry sand recorded a decrease in the final hydraulic conductivity values at lower energy levels by factors of 1.46, 1.33, 1.08 and 1.00 at RBSL, BSL, WAS and BSH compactive efforts, respectively. Similarly, 4 % bagasse ash treated foundry sand recorded a decrease in the final hydraulic conductivity values by factors of 1.61, 1.32, 1.17 and 0.70 at RBSL, BSL, WAS and BSH compactive efforts, respectively. Lower energies levels recorded more changes in its pores or voids after long period of hydration reaction due to products of formed hydrations filling the pores up: bigger pores experience greater impact on their pores than smaller pored specimen (specimen at higher compactive efforts). Generally, hydration products decrease void space with curing times and less pores are available for filling by the products of hydration for specimen at higher energy levels. Thus, bagasse ash treated foundry sand at lower energy levels records more positive impact on their final hydraulic conductivity values than that at higher energy levels.

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